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LEAD SUSCEPTIBILITY OF SEVERAL FUELS AS DETERMINED IN AN AIR-COOLED AIRCRAFT-ENGINE CYLINDER

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LEAD SUSCEPTIBILITY OF SEVERAL FUELS AS DETERMINED IN AN AIR-COOLED AIRCRAFT-ENGINE CYLINDER

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In order to determine the lead susceptibility of several fuels, leaded and unleaded fuels from the same stock were blended and tested in a full-scale air-cooled aircraft-engine cylinder.

The fuels used were S-4 reference fuel, virgin-base stock, aviation alkylate, neohexane, and blends of 25-percent benzene with 75-percent virgin-base stock and 25-percent toluene with 75-percent virgin-base stock.

Knock-limited performance data were obtained for each fuel, clear and with 6 ml TEL per gallon, for a range of fuel-air ratios from 0.05 or 0.08 to 0.115. Similar data were also obtained for S-4 reference fuel with 2.5 ml TEL per gallon in order to test more thoroughly lead response of a fuel between 0 and 2.5 ml TEL per gallon. Blends of the clear with the leaded fuels for intermediate concentrations of tetraethyl lead were then tested at fuel-air ratios of approximately 0.067 or 0.07 and 0.10 according to the procedure described in reference 1. Because the test equipment would not permit a low air flow it was necessary to test the virgin-base stock and the aromatic blends with intermediate concentrations of tetraethyl lead at a fuel-air ratio of 0.07 instead of 0.067.

Tests were conducted with an R-2800 cylinder mounted on a CUE crankcase. The apparatus is described in detail in reference 1. Two important alterations were made to the apparatus as described in the reference for the investigation reported herein. A thermocouple was embedded about one-sixteenth inch from the combustion-chamber wall at the exhaust end zone and this thermocouple rather than the rear spark-plug-boss thermocouple was used as a constant-temperature reference. The second alteration was the installation of an altitude exhaust system.

The engine operating conditions were as follows:

Compression ratio	7.5
Spark advance, deg B.T.C.	20
Engine speed, rpm	2000
Condition of fuel-air mixture	prevaporized
Inlet-mixture temperature, °F	240
Exhaust back pressure, inches of mercury absolute	15 ±0.2
Cylinder-head temperature at exhaust end zone, °F	350
Cooling-air temperature, °F	80 to 100

The temperature of the rear spark-plug bushing was approximately 400° F.

The exhaust pressure of 15 inches of mercury was chosen because data from this laboratory show that knock-limited power at lean fuel-air ratios is critically affected when the manifold pressure is within +10 or -5 inches of mercury of the exhaust pressure.

A comparison of unpublished data from this laboratory between cruising flight conditions and the engine operating conditions stated indicates that the test conditions were more severe than cruising.

The knock-limited indicated mean effective pressures and the indicated specific fuel consumptions for the mixture-response curves of S-4 reference fuel, clear and with 2.5 and 6 ml TEL per gallon, for a range of fuel-air ratios from approximately 0.050 to 0.115 are shown in figure 1. Corresponding data are also shown for intermediate blends of S-4 with S-4 plus 2.5 and 6 ml TEL per gallon at fuel-air ratios of approximately 0.067 and 0.10. Similar data for the other paraffins (virgin base, alkylate, and neohexane) and the aromatic blends (25 percent benzene and toluene with virgin base) are shown in figures 2 to 6, respectively. A mixture-response curve was run with 2.5 ml TEL per gallon only for S-4 reference fuel.

Cross plots for each fuel tested of the knock-limited indicated mean effective pressures plotted against concentrations of tetraethyl lead at constant fuel-air ratios of 0.067 or 0.07 and 0.10 are presented in figure 7. The points used in plotting the curves of figure 7 were taken from figures 1 to 6 at the intersection of the 0.067 or 0.07 and the 0.10 fuel-air-ratio ordinate and the estimated faired mixture-response curves through the data points.

The lead response of the paraffinic fuels and aromatic blends for different tetraethyl-lead concentrations at a lean fuel-air ratio (0.067 or 0.07) and at a rich fuel-air ratio (0.10) is given in table I. The results are given in terms of the knock-limited indicated mean effective pressure and in percentage increase in this quantity.

The tabulated values show that the percentage increase in knock-limited indicated mean effective pressure varies for the different paraffins tested. This result is true for all additions of tetraethyl lead and for both the lean and rich fuel-air ratios. At a fuel-air ratio of 0.10, however, the results for S-4 reference fuel showed fairly good agreement with those for virgin base and the results for aviation alkylate showed similar agreement with those for neohexane.

The two aromatic blends tested gave about the same percentage increase in knock-limited indicated mean effective pressure for any one addition of tetraethyl lead. This result is valid for both lean and rich fuel-air ratios. The aromatic blends were generally more responsive to tetraethyl-lead additions than were the paraffins, the only exception being at lean mixtures where neohexane gave a greater percentage increase in knock-limited power for all tetraethyl-lead concentrations than any of the other fuels tested.

Table I gives further evidence that tetraethyl lead is a more effective antiknock agent at lean mixtures than at rich mixtures, a characteristic which was considered in reference 2.

With S-4 reference fuel, a region of slight appreciation in performance was observed between 1 and 1.5 ml TEL per gallon as shown in figure 7. At higher lead concentrations, a greater response was observed although the incremental increase was smaller for the higher tetraethyl-lead concentrations. The other fuels were not thoroughly investigated in the range where this break occurred; consequently these fuels may or may not exhibit this peculiarity.

Tests of fuels containing from 0 to 6 ml TEL per gallon at fuel-air ratios from approximately 0.05 to 0.115 made in a full-scale air-cooled aircraft-engine cylinder show that:

1. For tetraethyl-lead concentrations in excess of 3 milliliters per gallon, the aromatic blends showed a greater percentage increase in knock-limited power than the paraffins with the exception of neohexane, which gave the greatest percentage increase of all the fuels tested at lean mixtures.

2. For any particular tetraethyl-lead addition, the percentage increase in knock-limited indicated mean effective pressure compared

to the clear fuel was about the same for the aromatic blends tested. The percentage increase in knock-limited mean effective pressure resulting from lead additions varied for the four paraffinic fuels tested.

3. A given lead concentration in any fuel tested permitted a greater percentage increase in knock-limited indicated mean effective pressure at lean mixtures than at rich mixtures.

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REFERENCES

1. Sanders, Newell D., Hensley, Reece V., and Breitwieser, Roland: Experimental Studies of the Knock-Limited Blending Characteristics of Aviation Fuels. I - Preliminary Tests in an Air-Cooled Cylinder. NACA ARR No. E4I28, 1944.

2. Barnett, Henry C., and Imming, Harry S.: The Effect of Engine Conditions on the Lead Susceptibility of Paraffinic Fuels. NACA ARR No. E4J02, 1944.

TABLE I - LEAD RESPONSES OF SIX FUELS FOR SEVEN DIFFERENT ADDITIONS OF TETRAETHYL LEAD IN A FULL-SCALE AIR-COOLED AIRCRAFT-ENGINE CYLINDER

[For fuel-air ratios of 0.067 or 0.07 and 0.10, the first row of values is permissible imep; the second row of values is percentage increase in imep]

Fuel	Fuel-air ratio	Concentration of tetraethyl lead (ml/gal)							
		0	0.5	1	2	3	4	5	6
S-4 reference	0.067	107 0	135 26.5	155 45	163 52.5	173 61.5	181 69	189 77	195 82
	.10	152 0	185 21.5	191 25.5	206 35.5	224 47.5	234 54	241 58.5	246 62
Virgin-base stock	0.07	66 0	76 15	82 24	90 36.5	97 47	104 57.5	110 66.5	116 76
	.10	96 0	110 14.5	118 23	130 35.5	138 44	145 51	150 56	155 61.5
Aviation alkylate	0.067	83 0	103 24	110 32.5	125 50.5	141 70	148.5 79	153 84	156 88
	.10	120 0	148 23	159 32.5	172 43.5	185 54	194 61.5	202 68	209 74
Neohexane	0.067	97 0	130 34	155 60	170 75	183 88.5	197 103	211 117.5	220 127
	.10	138 0	156 13	173 25.5	199 44	214 55	226 64	235 70	241 74.5
25% benzene +75% virgin base	0.07	59 0	78 32	86 46	95 61	103 74.5	108.5 84	113 91.5	117 98
	.10	91 0	109 20	116 27.5	126 38.5	141 55	151 66	159 75	165 81
25% toluene +75% virgin base	0.07	57 0	70.5 23.5	81 42	94 65	100 75.5	104.5 83.5	108 89.5	110 93
	.10	90 0	106+ 18	115 28	128 42	141 56.5	155 72	163 81	166.5 85

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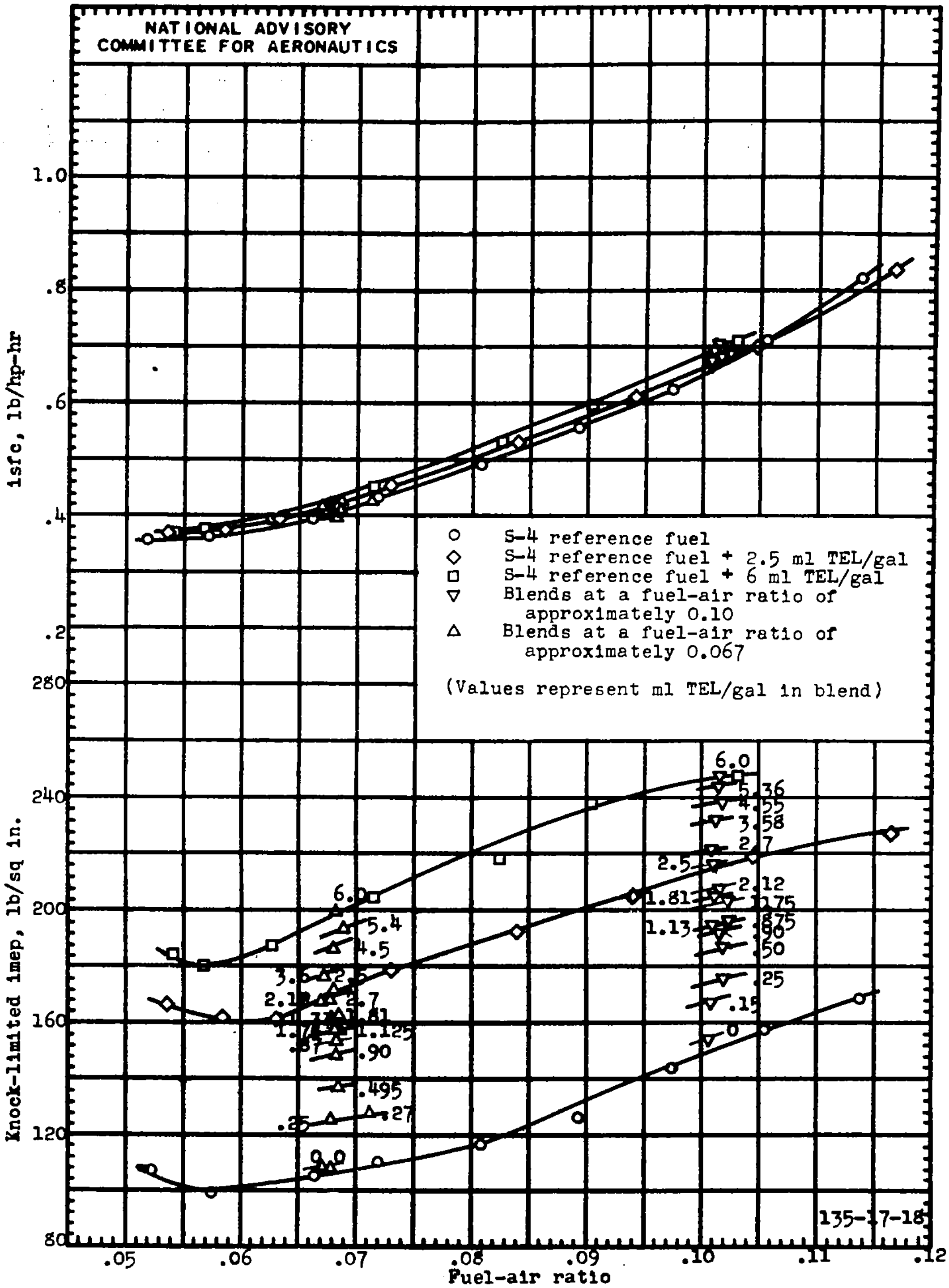

Figure 1. - The knock-limited performance of blends of S-4 reference fuel clear and with 2.5 and 6 ml TEL per gallon. Full-scale air-cooled aircraft-engine cylinder; spark advance, 20° B.T.C.; compression ratio, 7.5; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F; exhaust back pressure, 15 inches of mercury absolute.

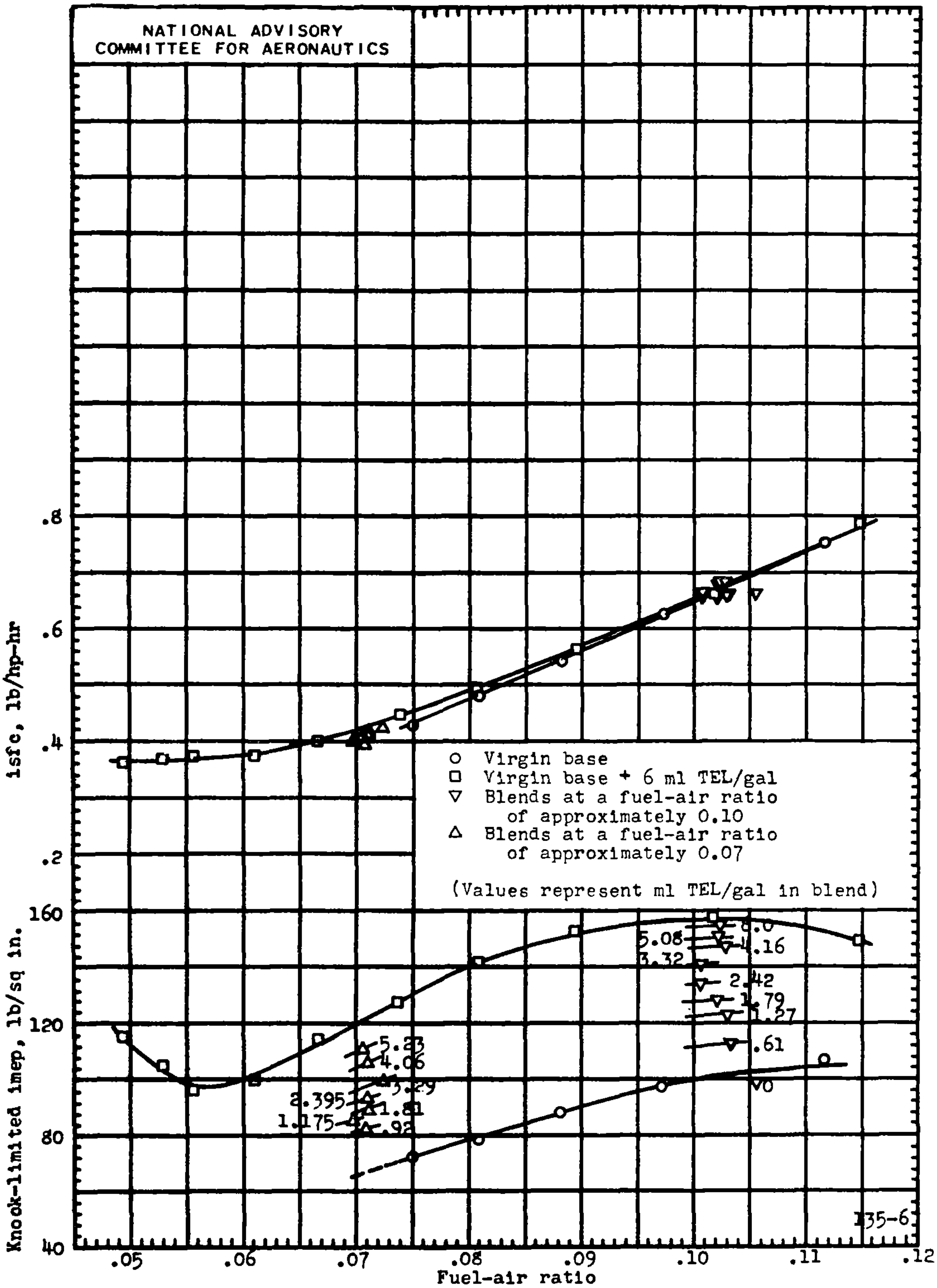

Figure 2. - The knock-limited performance of blends of virgin-base stock clear and with 6 ml TEL per gallon. Full-scale air-cooled aircraft-engine cylinder; spark advance, 20° B.T.C.; compression ratio, 7.5; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F; exhaust back pressure, 15 inches of mercury absolute.

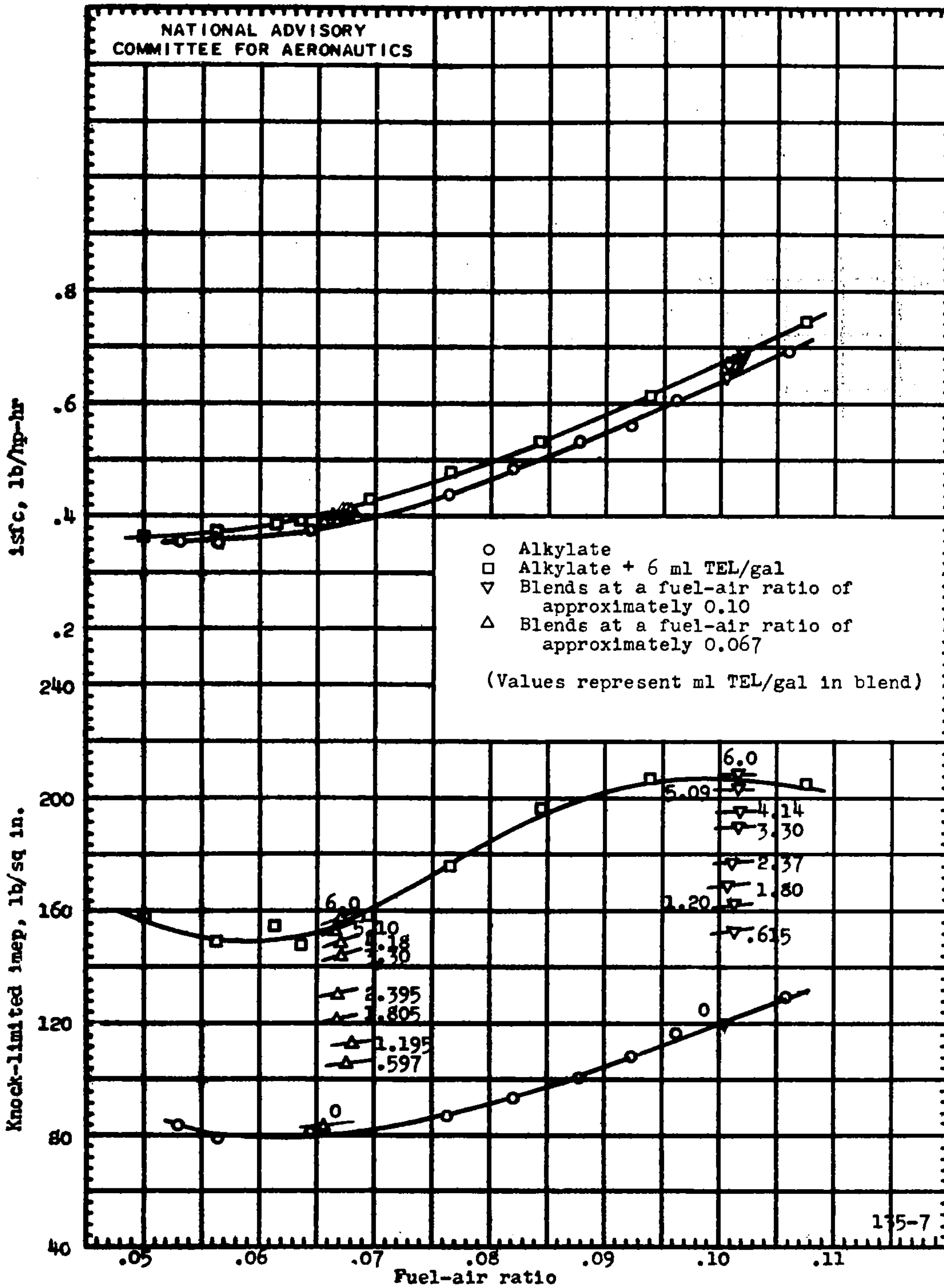

Figure 3. - The knock-limited performance of blends of alkylate clear and with 6 ml TEL per gallon. Full-scale air-cooled aircraft-engine cylinder; spark advance, 20° B.T.C.; compression ratio, 7.5; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F; exhaust back pressure, 15 inches of mercury absolute.

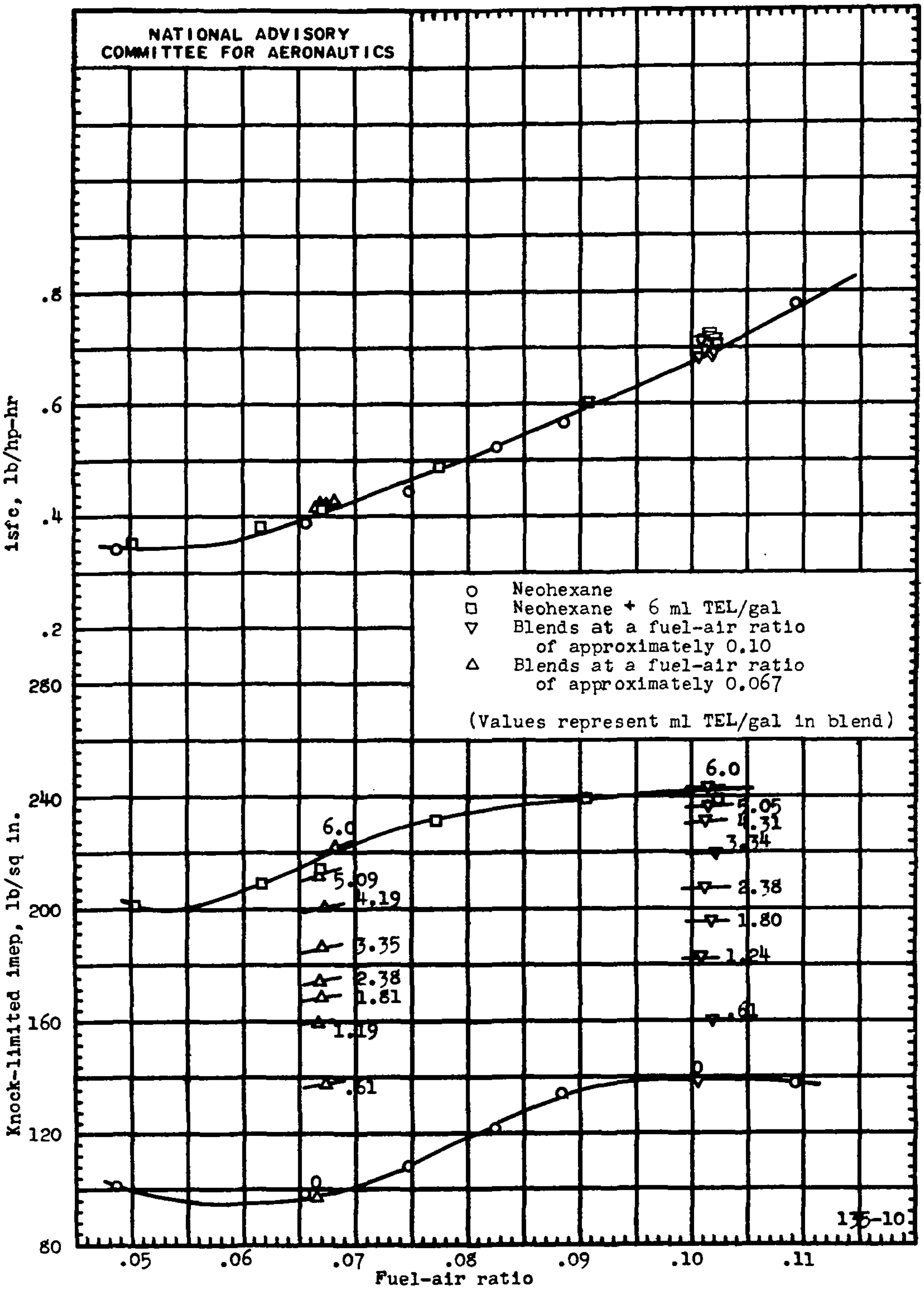

Figure 4. - The knock-limited performance of blends of neohexane clear and with 6 ml TEL per gallon. Full-scale air-cooled aircraft-engine cylinder; spark advance, 20° B.T.C.; compression ratio, 7.5; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F; exhaust back pressure, 15 inches of mercury absolute.

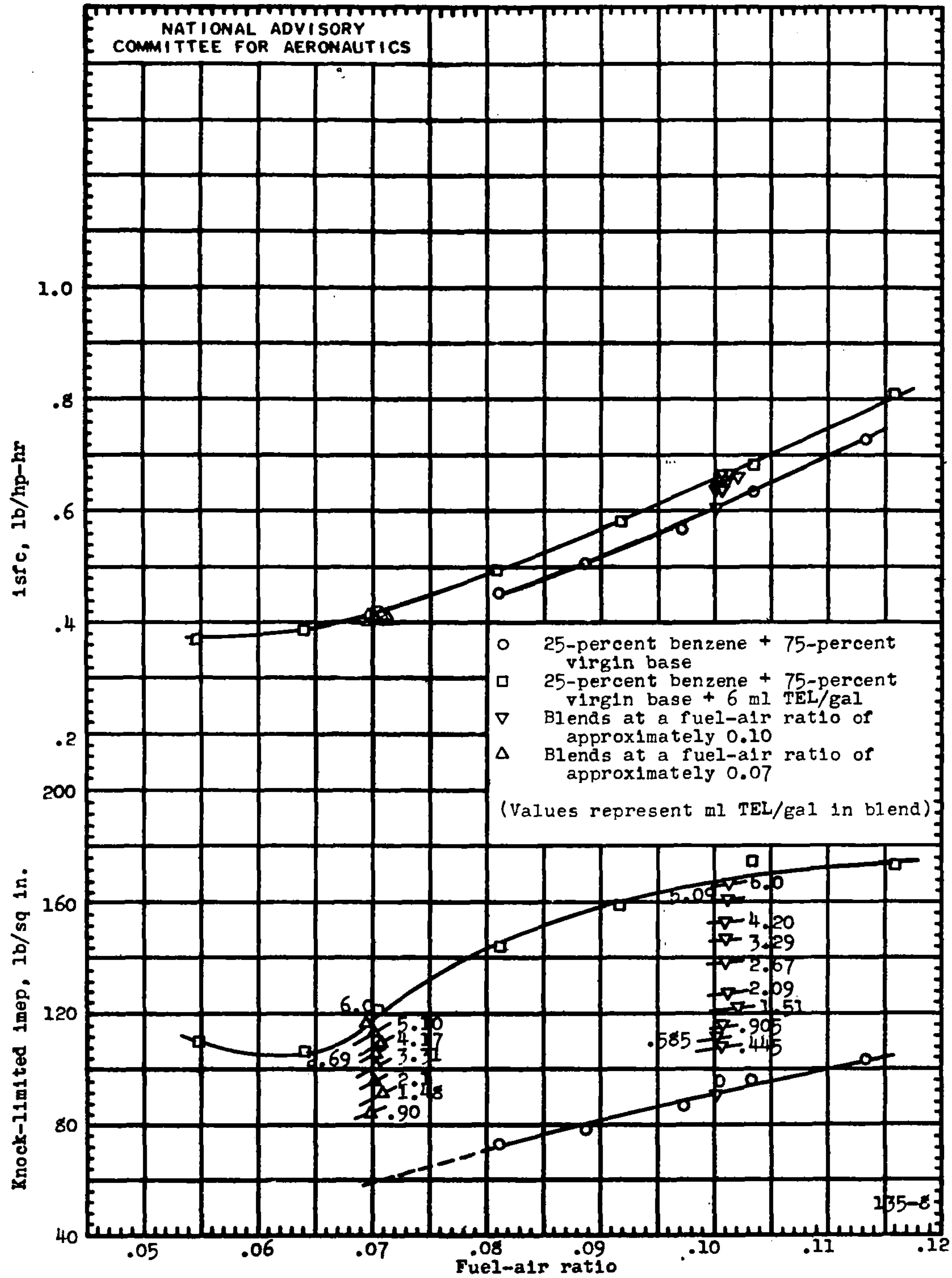

Figure 5. - The knock-limited performance of blends of 25-percent benzene plus 75-percent virgin-base stock clear and with 6 ml TEL per gallon. Full-scale air-cooled aircraft-engine cylinder; spark advance, 20° B.T.C.; compression ratio, 7.5; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F; exhaust back pressure, 15 inches of mercury absolute.

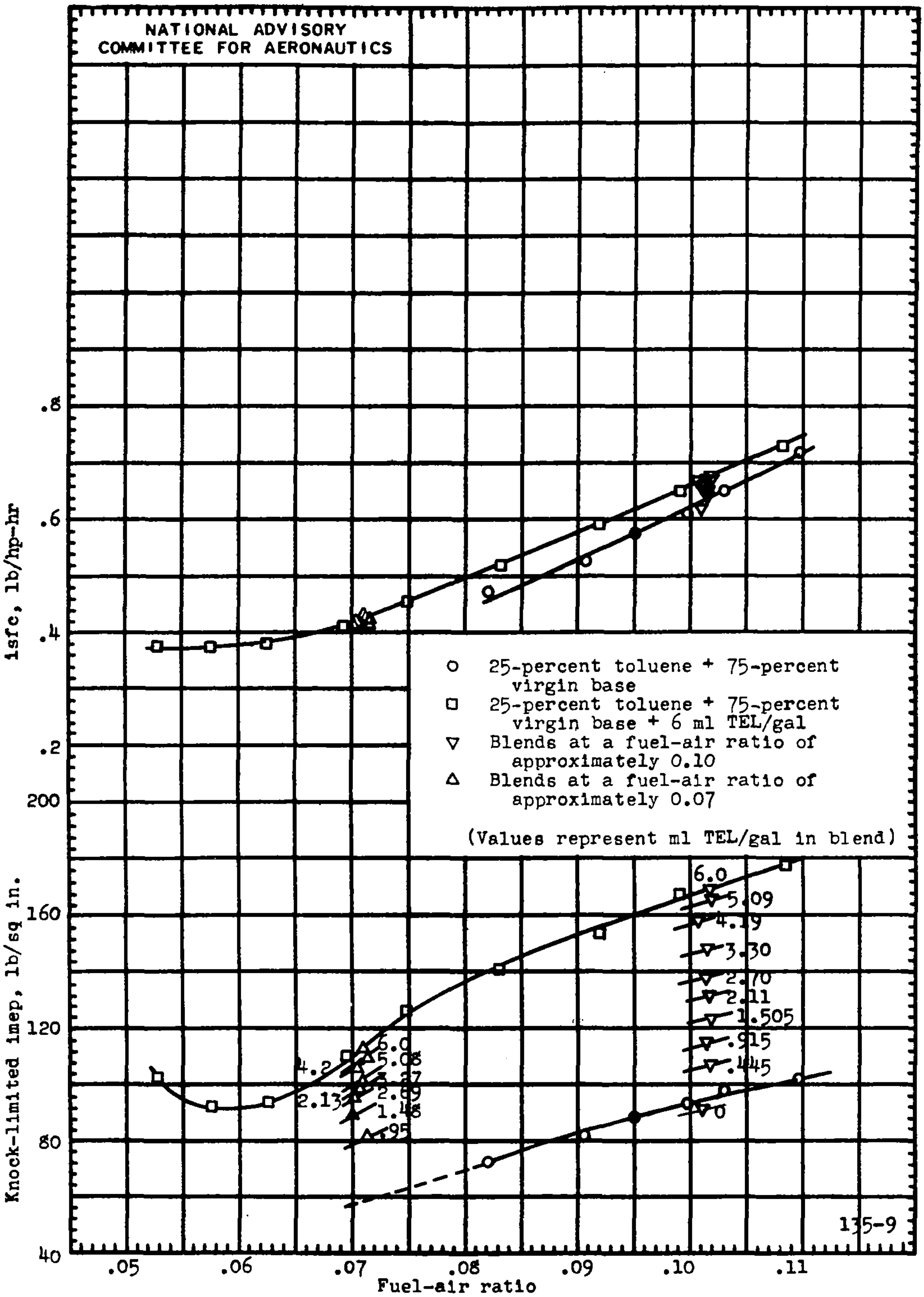

Figure 6. - The knock-limited performance of blends of 25-percent toluene plus 75-percent virgin-base stock clear and with 6 ml TEL per gallon. Full-scale air-cooled aircraft-engine cylinder; spark advance, 30° B.T.C.; compression ratio, 7.5; engine speed, 2000 rpm; inlet-mixture temperature, 240° F; cylinder-head temperature at exhaust end zone, 350° F; exhaust back pressure, 15 inches of mercury absolute.

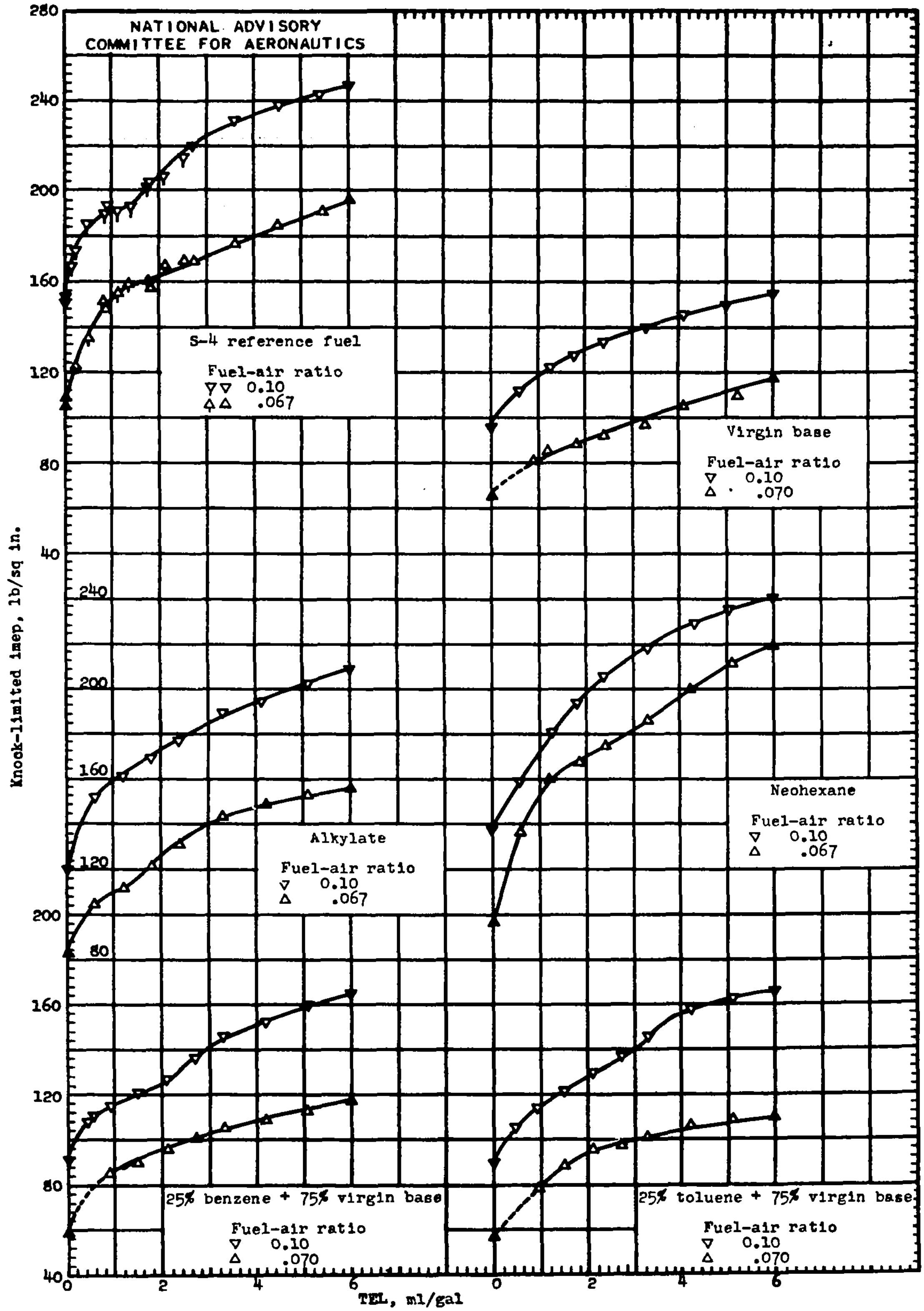

Figure 7. - Relation between knock-limited indicated mean effective pressure and lead concentration for several fuels at fuel-air ratios of 0.067 or 0.070 and 0.10.